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Kim

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(54) **METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE**

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H01L 21/8238 (2006.01)
H01L 29/10 (2006.01)
H01L 29/423 (2006.01)
H01L 29/49 (2006.01)

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CPC **H01L 27/088** (2013.01); **H01L 21/823842** (2013.01); **H01L 21/823885** (2013.01); **H01L 27/0922** (2013.01); **H01L 29/1033** (2013.01); **H01L 29/42364** (2013.01); **H01L 29/42376** (2013.01); **H01L 29/4966** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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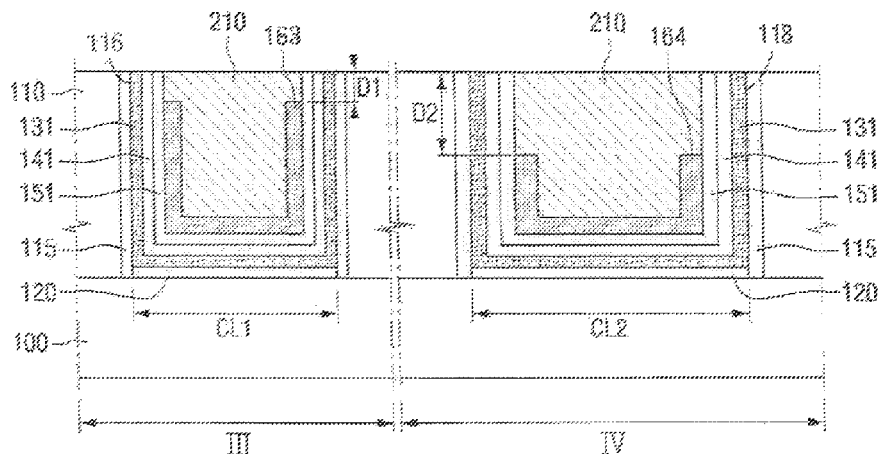
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(57) **ABSTRACT**

A method of manufacturing a semiconductor device comprises forming an interlayer insulating film on a semiconductor substrate, the interlayer insulating film including a trench, forming a work function metal layer in the trench, forming an insulating film on the work function metal layer, forming a sacrificial film on the insulating film and filling the trench, forming a sacrificial film pattern with a top surface disposed in the trench by etching the sacrificial film, forming an insulating film pattern by selectively etching a portion of the insulating film which is formed higher than the sacrificial film pattern, and forming a work function metal pattern with a top surface disposed in the trench by selectively etching a portion of the work function metal layer which is formed higher than the insulating film pattern.

20 Claims, 16 Drawing Sheets



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FIG. 1

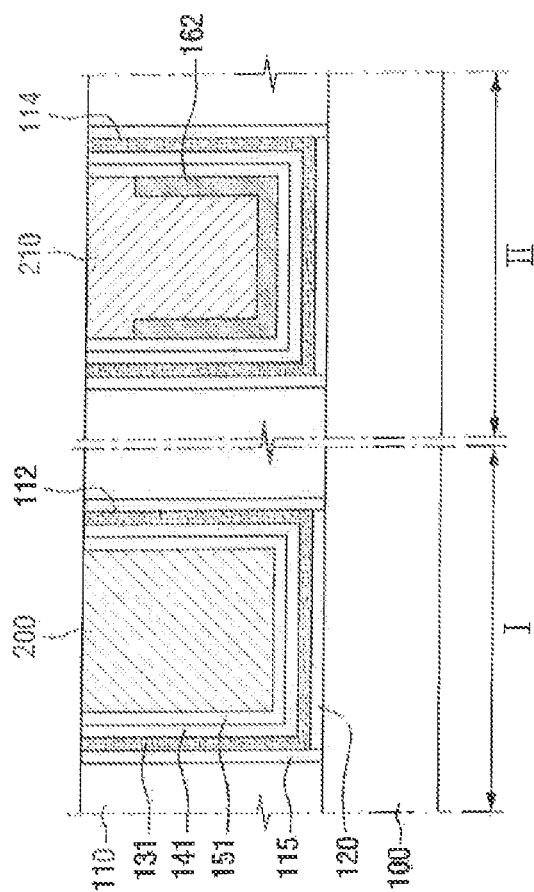


FIG. 2

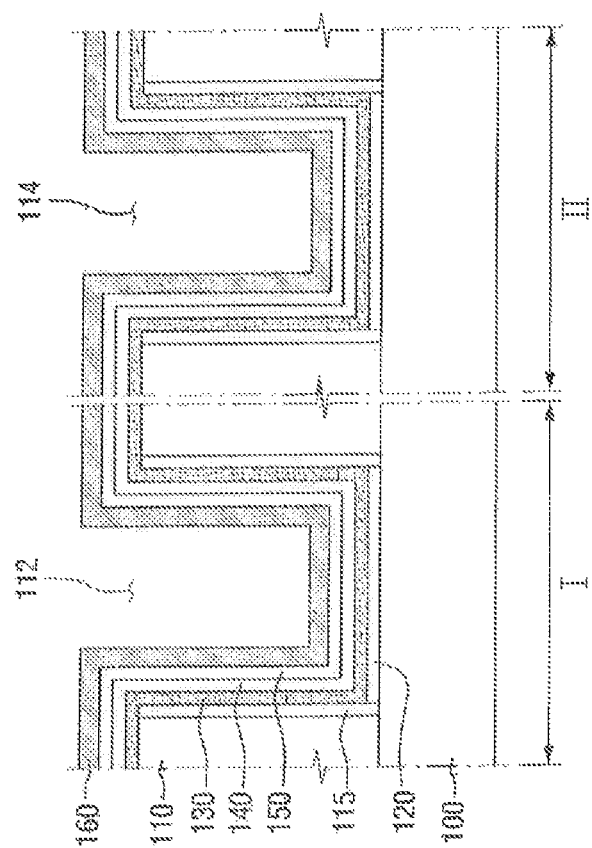


FIG. 3

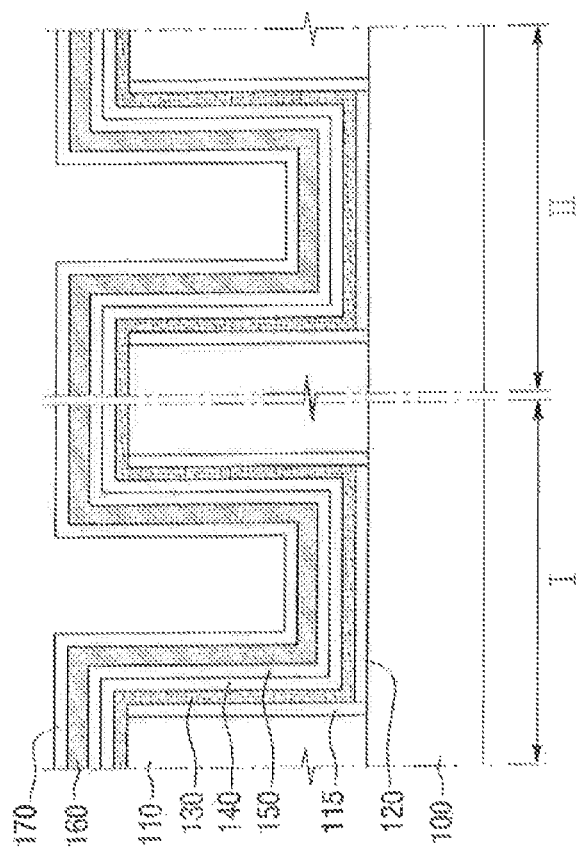


FIG. 4

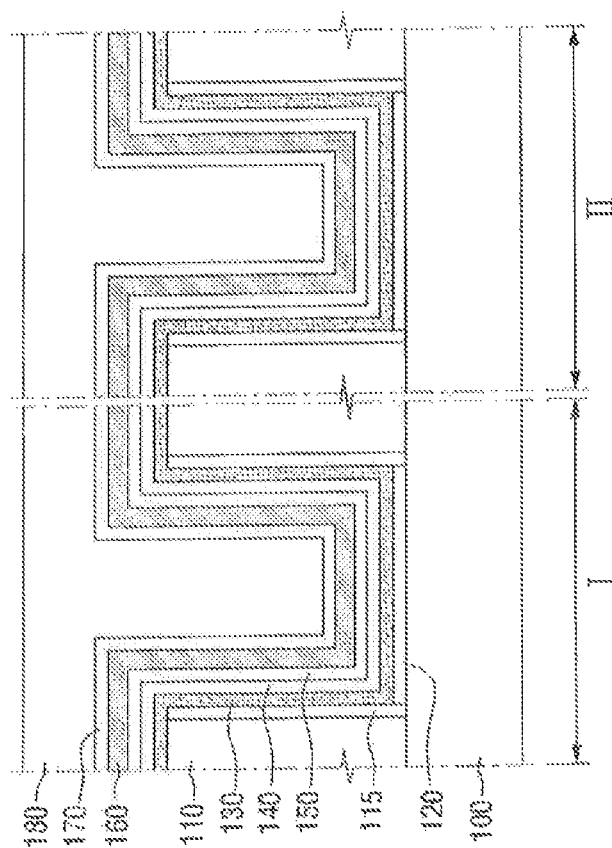


FIG. 5

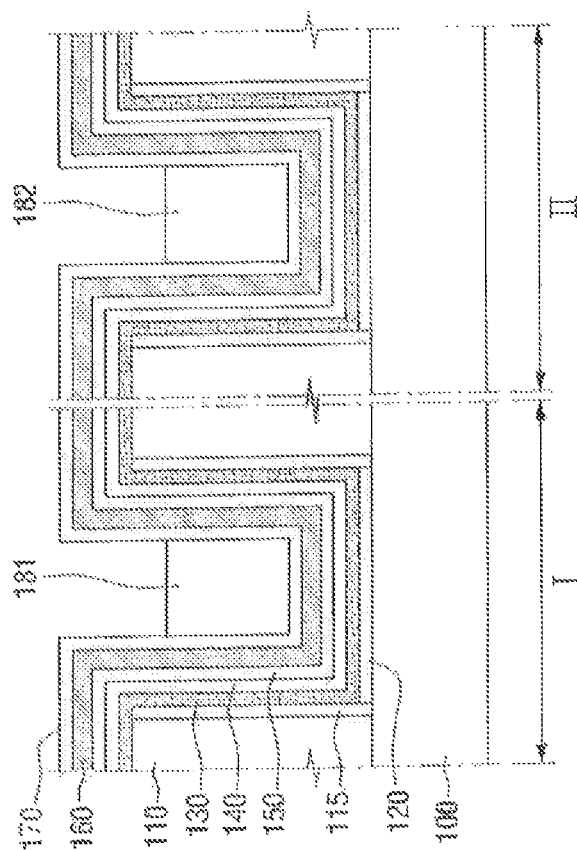


FIG. 6

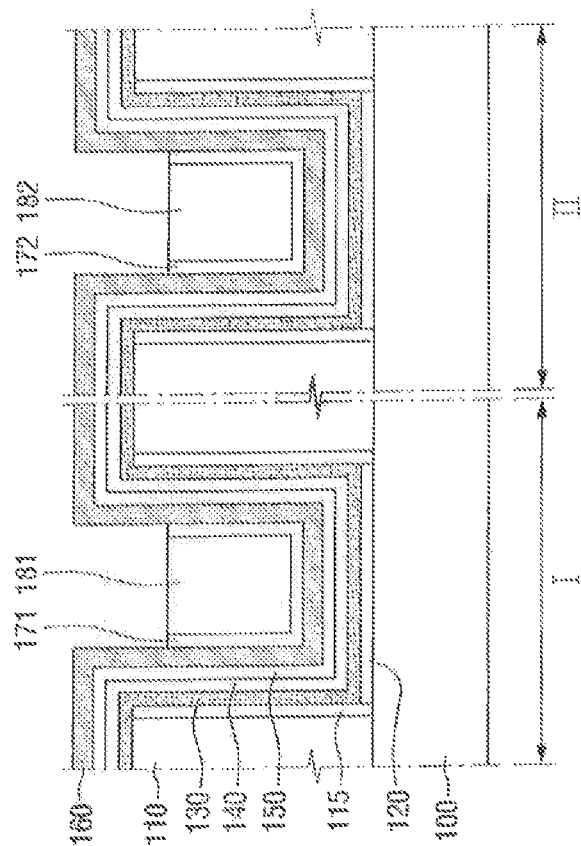


FIG. 3

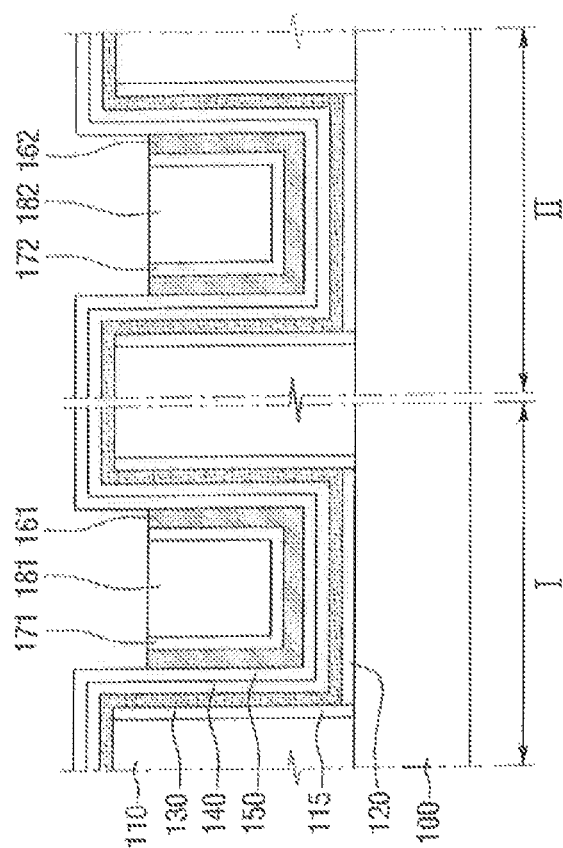


FIG. 8

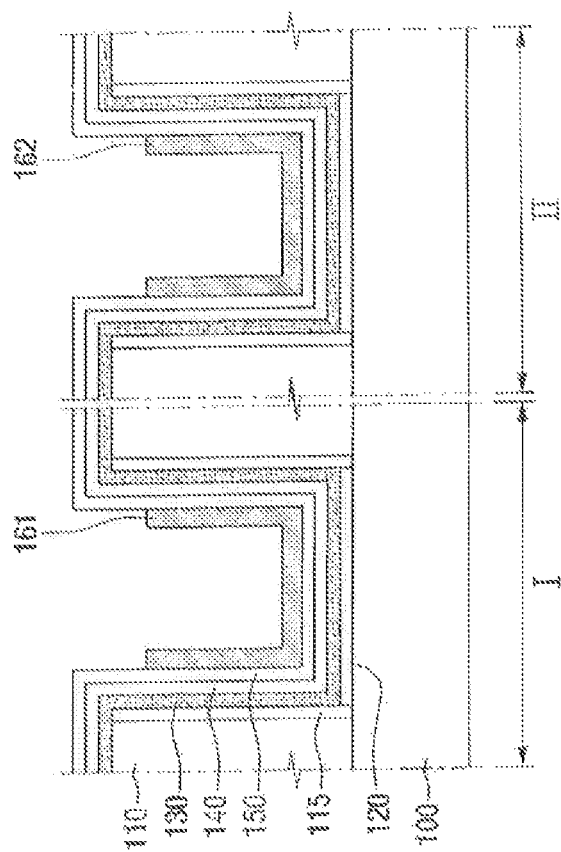


FIG. 9

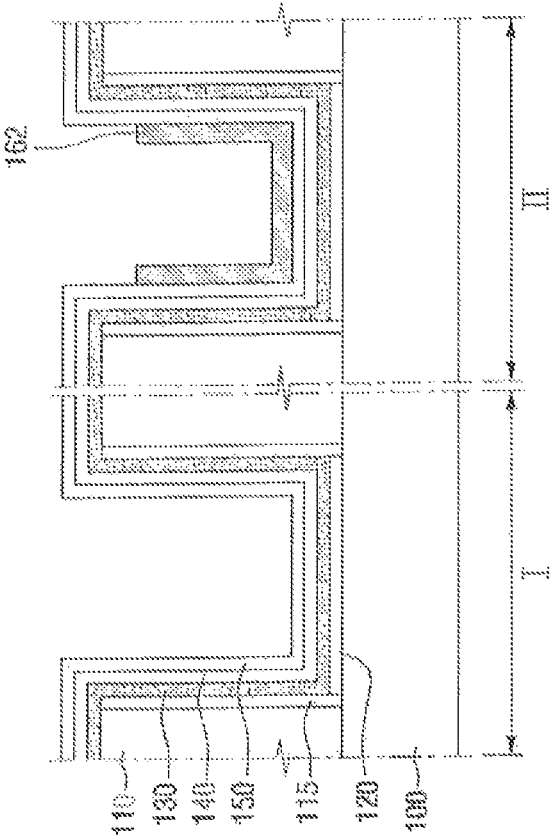


FIG. 10

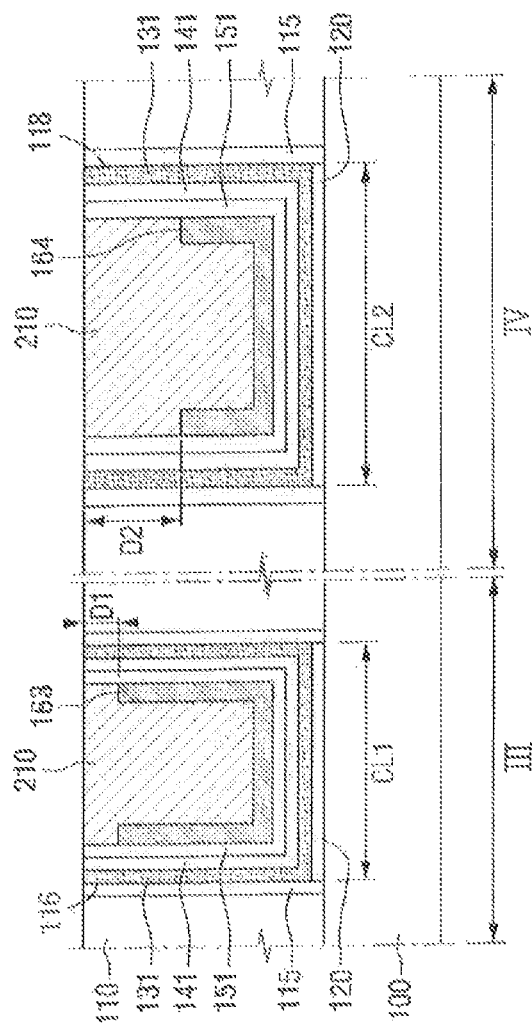


FIG. 11

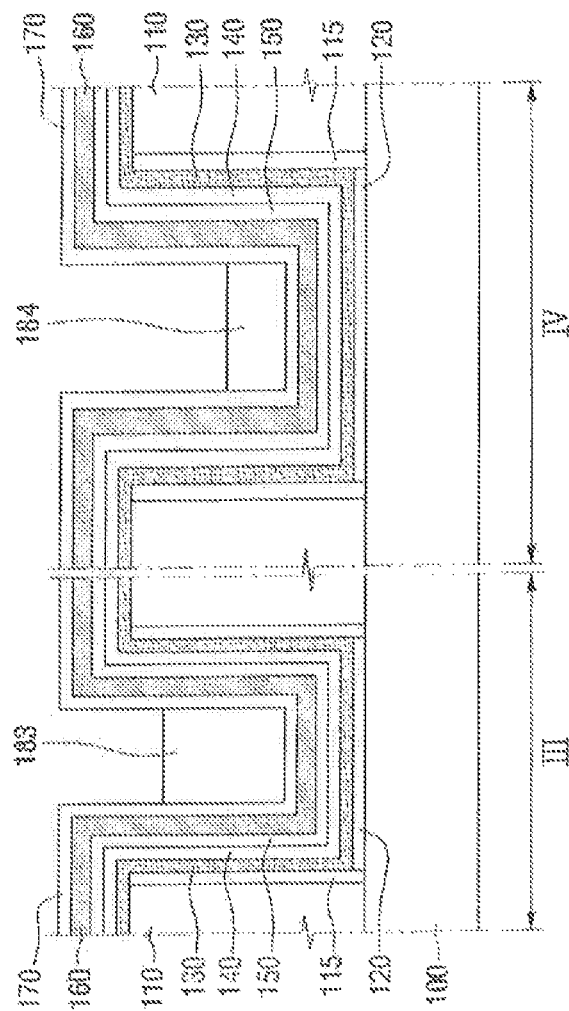


FIG. 12

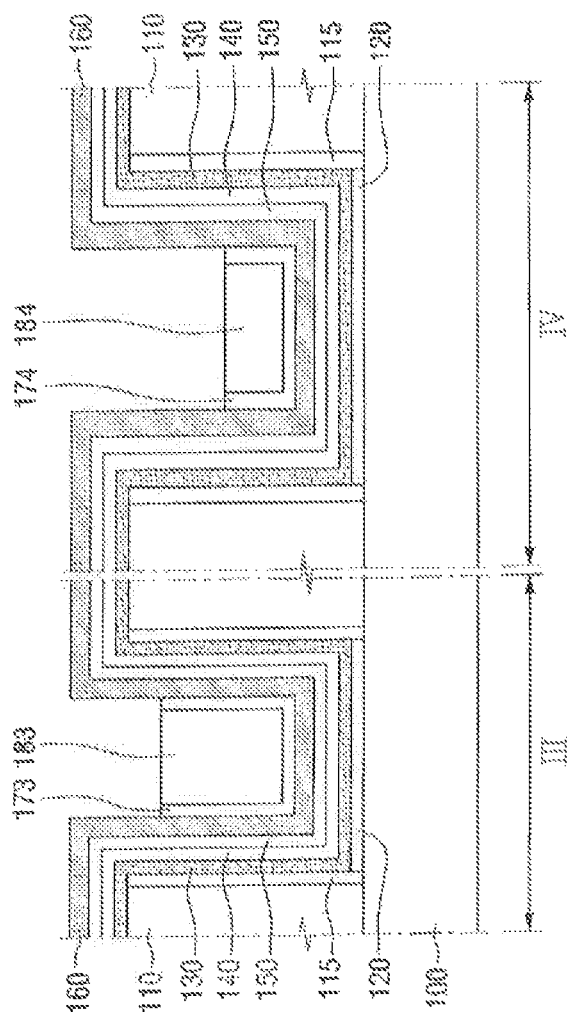


FIG. 13

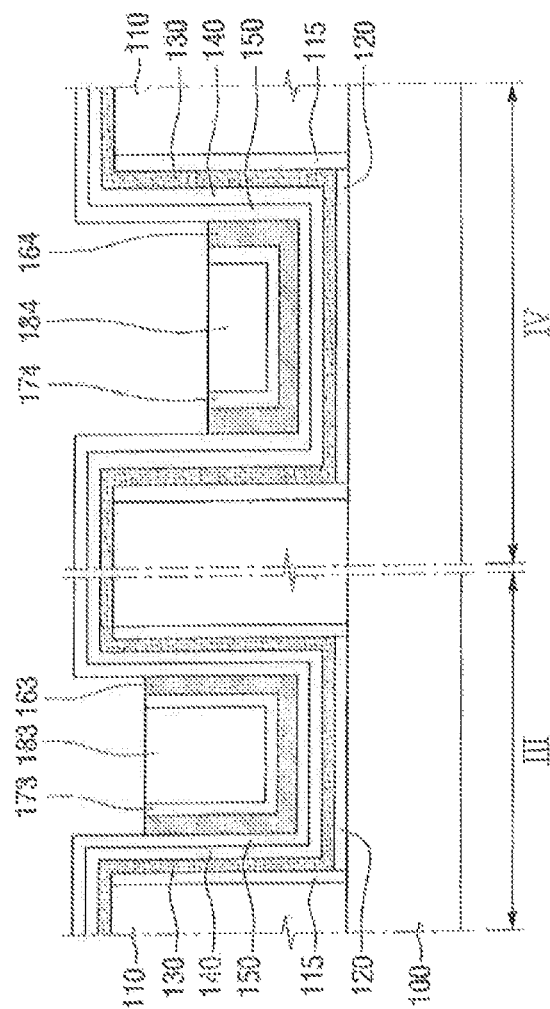


FIG. 14

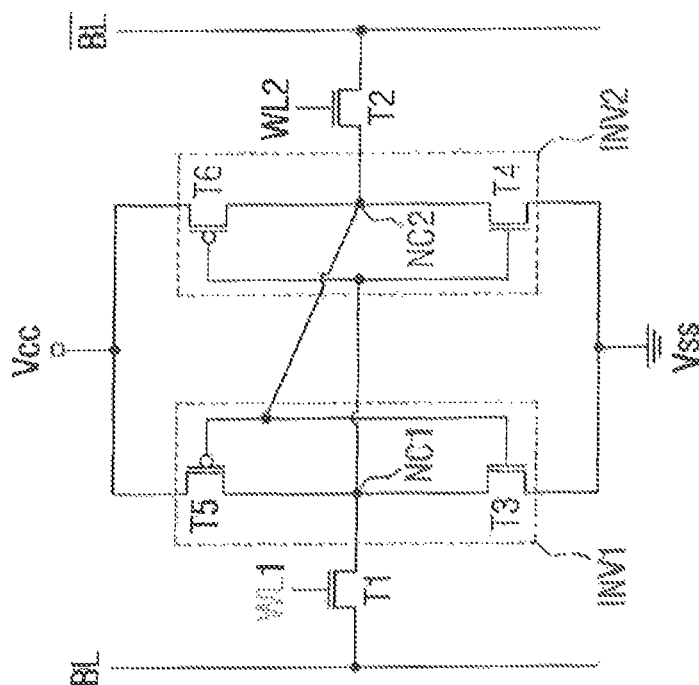


FIG. 15

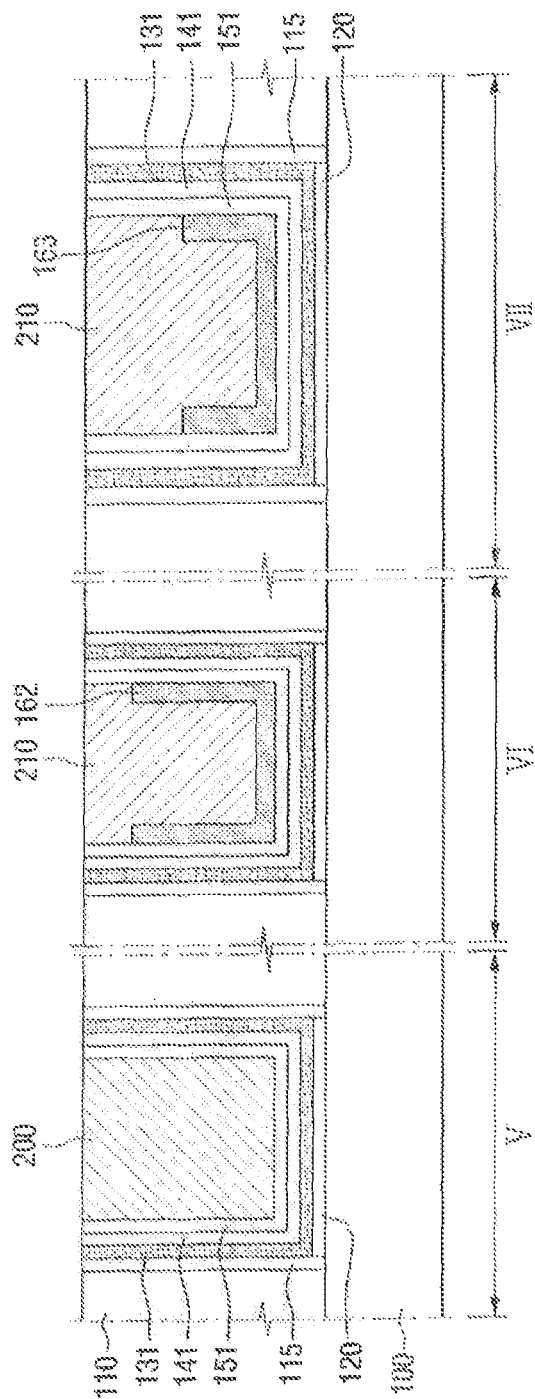
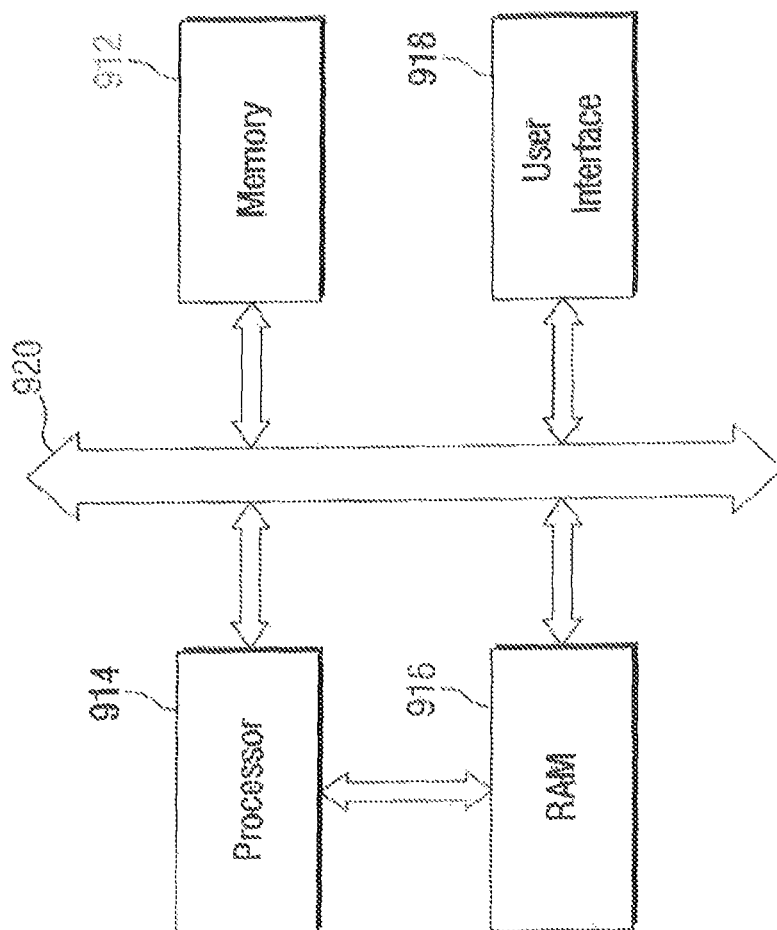


FIG. 16



1

METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE

This application is a continuation of U.S. application Ser. No. 14/469,013 filed on Aug. 26, 2014, which is a continuation of U.S. application Ser. No. 13/720,435 filed on Dec. 19, 2012, which claims priority from Korean Patent Application No. 10-2012-0046358 filed on May 2, 2012 in the Korean Intellectual Property Office, the disclosure of which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

The present invention relates to a method of manufacturing a semiconductor device.

DISCUSSION OF THE RELATED ART

Metal oxide semiconductor (MOS) transistors have polysilicon gate electrodes. Polysilicon can withstand high temperatures and can block the implantation of doped atoms into a channel region.

However, since polysilicon has a higher resistance than that of most metals, polysilicon gate electrodes may operate at slower speeds than metal gates. A replacement metal gate (RMG) process is a high-temperature process performed while polysilicon is present on a semiconductor substrate. After the high-temperature process, the polysilicon is removed and then replaced by a metal, thereby forming a replacement metal gate electrode.

SUMMARY

Embodiments of the present invention provide a method of manufacturing a semiconductor device with improved metal-fill characteristics.

According to an embodiment of the present invention, there is provided a method of manufacturing a semiconductor device, the method comprising forming an interlayer insulating film on a semiconductor substrate, the interlayer insulating film comprising a trench, forming a work function metal layer in the trench, forming an insulating film on the work function metal layer, forming a sacrificial film on the insulating film, the sacrificial film filling the trench, forming a sacrificial film pattern by etching the sacrificial film, a top surface of the sacrificial film pattern being disposed in the trench, forming an insulating film pattern by selectively etching a portion of the insulating film which is formed higher than the sacrificial film pattern, and forming a work function metal pattern with a top surface disposed in the trench by selectively etching a portion of the work function metal layer which is formed higher than the insulating film pattern.

According to an embodiment of the present invention, there is provided a method of manufacturing a semiconductor device, the method comprising forming an interlayer insulating film on a semiconductor substrate, the interlayer insulating film comprising a first trench having a first width and a second trench having a second width different from the first width, forming a work function metal layer in the first and second trenches, forming an insulating film on the work function metal layer formed in the first and second trenches, forming a sacrificial film on the insulating film and filling the first and second trenches, forming first and second sacrificial film patterns with top surfaces disposed in the first and second trenches, respectively, by etching the sacrificial film, forming a first insulating film pattern by selectively etching a portion of the insulating film which is formed higher than the first

2

sacrificial film pattern and forming a second insulating film pattern by selectively etching a portion of the insulating film which is formed higher than the second sacrificial film pattern, and forming a first work function metal pattern with a top surface disposed in the first trench by selectively etching a portion of the work function metal layer which is formed higher than the first insulating film pattern and forming a second work function metal pattern with a top surface disposed in the second trench by selectively etching a portion of the work function metal layer which is formed higher than the second insulating film pattern, wherein a first depth from a top surface of the interlayer insulating film to the top surface of the first work function metal pattern is different from a second depth from the top surface of the interlayer insulating film to the top surface of the second work function metal pattern.

According to an embodiment of the present invention, there is provided a semiconductor device comprising a semiconductor substrate, an inter-layer insulating film formed on a top surface of the semiconductor substrate, wherein the inter-layer insulating film includes a first trench on a first region of the semiconductor substrate, a first work-function metal pattern formed, in the first trench, on a side surface of the inter-layer insulating film and on the top surface of the semiconductor substrate, wherein an end of the first work-function metal pattern does not extend up to a top surface of the inter-layer insulating film, and a first metal gate structure pattern formed on the first work-function metal pattern in the trench.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the present invention will become more apparent by the description with reference to the attached drawings, in which:

FIG. 1 is a cross-sectional view illustrating a semiconductor device according to an embodiment of the present invention;

FIGS. 2 through 9 are cross-sectional views illustrating intermediate processes included in a method of manufacturing a semiconductor device according to an embodiment of the present invention;

FIG. 10 is a cross-sectional view illustrating a semiconductor device according to an embodiment of the present invention;

FIGS. 11 through 13 are cross-sectional views illustrating intermediate processes included in a method of manufacturing a semiconductor device according to an embodiment of the present invention;

FIG. 14 is a circuit diagram illustrating a semiconductor device according to an embodiment of the present invention;

FIG. 15 is a cross-sectional view illustrating a semiconductor device according to an embodiment of the present invention; and

FIG. 16 is a block diagram illustrating an electronic system to which a semiconductor device according to the embodiments of the present invention is applied.

DETAILED DESCRIPTION OF THE EMBODIMENTS

It will be understood that when an element or layer is referred to as being “on” or “connected to” another element or layer, it can be directly on or connected to the other element or layer or intervening elements or layers may be present. Like numbers may refer to like or similar elements throughout the specification and the drawings. As used herein, the

term “and/or” includes any and all combinations of one or more of the associated listed items.

The use of the terms “a” and “an” and “the” and similar referents in the context of describing the invention (especially in the context of the following claims) may be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context.

FIG. 1 is a cross-sectional view illustrating a semiconductor device according to an embodiment of the present invention.

Referring to FIG. 1, a semiconductor substrate **100** may include a first region I and a second region II. In an embodiment, the first region I may be a region in which an N-type field effect transistor (NFET) is formed, and the second region II may be a region in which a P-type field effect transistor (PFET) is formed.

According to an embodiment, the semiconductor substrate **100** may be a silicon substrate, a gallium arsenide substrate, a silicon germanium substrate, a ceramic substrate, a quartz substrate or a glass substrate for display or may be a semiconductor on insulator (SOI) substrate. However, the embodiments of the present invention are not limited thereto, and various materials that may form the semiconductor substrate **100** can be used.

An interlayer insulating film **110** formed on the semiconductor substrate **100** may include a first trench **112** and a second trench **114**. The first trench **112** may be formed on the first region I of the semiconductor substrate **100**, and the second trench **114** may be formed on the second region II of the semiconductor substrate **100**.

A plurality of functional film patterns that constitute, e.g., an NFET may be formed in the first trench **112**. According to an embodiment, the functional film patterns may include an interface film pattern **120**, a gate insulating film pattern **131**, a first conductive film pattern **141**, a second conductive film pattern **151**, and a first metal gate structure pattern **200**.

The interface film pattern **120** may prevent a poor interface from occurring between the semiconductor substrate **100** and the gate insulating film pattern **131**. According to an embodiment, the interface film pattern **120** may include a low-k material layer with a dielectric constant (k) of about 9 or less (e.g., a silicon oxide film with a dielectric constant of about 4) or a silicon oxynitride film with a dielectric constant of about 4 to about 8 according to the content of oxygen atoms and nitrogen atoms. Alternatively, the interface film pattern **110** may be made of silicate or a combination of low-k material layers, e.g., a combination of the silicon oxide film and the silicon oxynitride film.

The gate insulating film pattern **131** may be formed on the interface film pattern **120**. According to an embodiment, the gate insulating film pattern **131** may be formed in a ‘U’ shape along inner sidewalls of the first trench **120** and a top surface of the interface film pattern **120**. The gate insulating film pattern **131** according to an embodiment is shaped like “U” when the semiconductor device is formed using a replacement metal gate (RMG) process.

According to an embodiment, the gate insulating film pattern **131** may contain a high-k material. According to an embodiment, the gate insulating film pattern **131** may contain a material of HfO_2 , ZrO_2 , Ta_2O_5 , TiO_2 , SrTiO_3 , or $(\text{Ba,Sr})\text{TiO}_3$. According to an embodiment, the gate insulating film pattern **131** may be formed to a predetermined thickness according to the type or material of the gate insulating film pattern **131**. For example, according to an embodiment, when the gate insulating film pattern **131** is HfO_2 , the gate insulating film pattern **131** may be formed to a thickness of about 50 Å or less (about 5 Å to about 50 Å).

The first conductive film pattern **141** and the second conductive film pattern **151** may be formed on the gate insulating film pattern **131**. In an embodiment, the first conductive film pattern **141** and the second conductive film pattern **151** may be formed in a ‘U’ shape. In an embodiment, each of the first conductive film pattern **141** and the second conductive film pattern **151** may include, for example, a metal nitride film. According to an embodiment, the first conductive film pattern **141** may include a TiN film, and the second conductive film pattern **151** may include a TaN film. However, the embodiments of the present invention are not limited thereto.

Each of the first conductive film pattern **141** and the second conductive film pattern **151** may be formed to a predetermined thickness according to the type or material thereof. For example, according to an embodiment, when the first conductive film pattern **141** includes TiN, the first conductive film pattern **141** may be formed to a thickness of about 5 Å to about 40 Å. According to an embodiment, when the second conductive film pattern **151** includes TaN, the second conductive film pattern **151** may be formed to a thickness of about 5 Å to about 30 Å.

The first metal gate structure pattern **200** may be formed on the second conductive film pattern **151**. The first metal gate structure pattern **200** may fill the first trench **112** on the second conductive film pattern **151**. According to an embodiment, the first metal gate structure pattern **200** may include an N-type work function metal pattern for improving a work function of the NFET and a metal gate pattern. Examples of the N-type work function metal may include, but are not limited to, TiAl, TiAlN, TaC, TiC, and HfSi. Examples of the metal gate may include, but are not limited to, Al and W.

A plurality of functional film patterns that constitute, e.g., a PFET may be formed in the second trench **114**. According to an embodiment, the functional film patterns may include an interface film pattern **120**, a gate insulating film pattern **131**, a first conductive film pattern **141**, a second conductive film pattern **151**, a work function metal pattern **162**, and a second metal gate structure pattern **210**.

According to an embodiment, the interface film pattern **120**, the gate insulating film pattern **131**, and the first and second conductive film patterns **141** and **151** formed in the second trench **114**, respectively, are identical or substantially identical to the interface film pattern **120**, the gate insulating film pattern **131**, and the first and second conductive film patterns **141** and **151** formed in the first trench **112**.

The work function metal pattern **162** may be formed on the second conductive film pattern **151**. According to an embodiment, the work function metal pattern **162** may be formed in a ‘U’ shape on the second conductive film pattern **151**.

In an embodiment, a topmost surface of the work function metal pattern **162** (e.g., two ends of the work function metal pattern **162** formed in a ‘U’ shape) may not extend up to a top surface of the second trench **114** and may be located within the second trench **114**. The shape of the work function metal pattern **162** can improve metal-fill characteristics of the second metal gate structure pattern **210** formed on the work function metal pattern **162**.

As the size of the semiconductor device decreases, the width of the first and second trenches **112** and **114** decreases. When the two ends of the work function metal pattern **162** extend up to the top surface of the second trench **114** unlike what is illustrated in FIG. 1, the entrance of the second trench **114** becomes narrow, which may result in a deterioration of metal-fill characteristics of the second metal gate structure pattern **210** to be filled in the second trench **114** in a subsequent process. Accordingly, in an embodiment, the topmost surface (e.g., the two ends) of the work function metal pattern

5

162 is not extended to the top surface of the second trench 114. As a result, the entrance region of the second trench 114 is wide enough to allow the second metal gate structure pattern 210 to be reliably formed in a subsequent process.

In an embodiment, the work function metal pattern 162 may be a P-type work function metal pattern to improve a work function of, e.g., a PFET. In some embodiments of the present invention, the work function metal pattern 162 may be, e.g., a metal nitride film. According to an embodiment, the work function metal pattern 162 may be, but is not limited to, a TiN film.

The second metal gate structure pattern 210 may be formed on the work function metal pattern 162. The second metal gate structure pattern 210 may fill the second trench 114 on the work function metal pattern 162. According to an embodiment, the second metal gate structure pattern 210 may include an additional P-type work function metal pattern for improving the work function of the PFET and a metal gate pattern.

A spacer 115 made of an insulating film may be formed on two opposite sides of each of the first trench 112 and the second trench 114. Although in FIG. 1 the spacer 115 has a pillar shape, the shape of the spacer 115 is not limited thereto. In an embodiment of the present invention, the spacer 115 may be shaped like "L".

Hereinafter, a method of manufacturing a semiconductor device according to an embodiment of the present invention is described with reference to FIGS. 1 through 9.

FIGS. 2 through 9 are cross-sectional views illustrating intermediate processes included in a method of manufacturing a semiconductor device according to an embodiment of the present invention.

Referring to FIG. 2, an interlayer insulating film 110 including a first trench 112 is formed on a first region I of a semiconductor substrate 100, and the interlayer insulating film 110 including a second trench 114 is formed on a second region II of the semiconductor substrate 100.

According to an embodiment, each of the first and second trenches 112 and 114 of the interlayer insulating film 110 may be formed by an RMG (Replacement Metal Gate) process.

A dummy gate structure is formed on each of the first and second regions I and II of the semiconductor substrate 100. A spacer 115 is formed on two opposite sides of the dummy gate structure. An interlayer insulating film 110 is formed on the semiconductor substrate 100 and covers the dummy gate structure. The interlayer insulating film 110 is planarized until a top surface of the dummy gate structure formed on each of the first and second regions I and II is exposed. A first trench 112 is formed by removing the dummy gate structure having the exposed top surface on the first region I, and a second trench 114 is formed by removing the dummy gate structure having the exposed top surface on the second region II.

After the first and second trenches 112 and 114 are formed, an interface film pattern 120 is formed on an exposed surface of the semiconductor substrate 100 by, e.g., a thermal oxidation process. According to an embodiment, the interface film pattern 120 may be made of a low-k material layer with a dielectric constant (k) of about 9 or less. The interface film pattern 120 can prevent a poor interface from occurring between the semiconductor substrate 100 and a gate insulating film pattern 131.

A gate insulating film 130, a first conductive film 140, and a second conductive film 150 are sequentially formed on the interface film pattern 120 in each of the first and second trenches 112 and 114. According to an embodiment, the gate insulating film 130, the first conductive film 140 and the second conductive film 150 may be formed by atomic layer

6

deposition (ALD), chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), or physical vapor deposition (PVD). The gate insulating film 130, the first conductive film 140, and the second conductive film 150 may be conformally formed along a top surface of the interlayer insulating film 110, side surfaces of the first and second trenches 112 and 114, and a top surface of the interface film pattern 120.

According to an embodiment, the gate insulating film 130 may contain a high-k material, for example, a material of HfO_2 , ZrO_2 , Ta_2O_5 , TiO_2 , SrTiO_3 , or $(\text{Ba,Sr})\text{TiO}_3$. According to an embodiment, the first conductive film 140 and the second conductive film 150 may include metal nitride films, for example, a TiN film and a TaN film, respectively.

A work function metal layer 160 is formed on the second conductive film 150 in each of the first and second trenches 112 and 114. In an embodiment, the work function metal layer 160 may include a P-type work function metal for improving a work function of, e.g., a PFET. According to an embodiment, the work function metal layer 160 may include, but is not limited to, TiN.

In an embodiment of the present invention, the work function metal layer 160 may be thicker than the first conductive film 140. In an embodiment of the present invention, the work function metal layer 160 may be thicker than the first and second conductive films 140 and 150.

Referring to FIG. 3, an insulating film 170 is formed on the work function metal layer 160. According to an embodiment, the insulating film 170 may be formed on the work function metal layer 160 by atomic layer deposition (ALD), chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), or physical vapor deposition (PVD). As shown in FIG. 3, the insulating film 170 may be conformally formed along the work function metal layer 160.

In an embodiment, the insulating film 170 may be, for example, an oxide film. According to an embodiment, the insulating film 170 may be an oxide film having an etch selectivity with respect to the work function metal layer 160. According to an embodiment, the insulating film 170 may be an oxide film having an etch selectivity with respect to the work function metal layer 160 and a sacrificial film 180.

Referring to FIG. 4, the sacrificial film 180 is formed on the insulating film 170. The sacrificial film 180 may fill the first and second trenches 112 and 114. In an embodiment, the sacrificial film 180 may include an organic material. In an embodiment of the present invention, the sacrificial film 180 may include, but is not limited to, photoresist.

Referring to FIG. 5, the sacrificial film 180 is etched, forming a first sacrificial film pattern 181 with a top surface disposed within the first trench 112 and a second sacrificial film pattern 182 with a top surface disposed within the second trench 114.

According to an embodiment, the sacrificial film 180 is etched until the insulating film 170 formed under the sacrificial film 180 is exposed. A top surface of the etched sacrificial film 180 may have the same or substantially the same height as a top surface of the insulating film 170. The etched sacrificial film 180 is etched again for a predetermined period of time, forming the first sacrificial film pattern 181 and the second sacrificial film pattern 182 respectively having top surfaces disposed in the first trench 112 and the second trench 114, respectively. According to an embodiment, the sacrificial film 180 is etched twice to thereby form the first and second sacrificial film patterns 181 and 182. Alternatively, the sacrificial film 180 may be etched once to thereby form the first and second sacrificial film patterns 181 and 182.

Referring to FIG. 6, the insulating film 170 formed higher than the first and second sacrificial film patterns 181 and 182 is selectively etched forming first and second insulating film patterns 171 and 172 in the first and second trenches 112 and 114, respectively. A portion of the insulating film 170 which is formed higher than the first sacrificial film pattern 181 is etched using the etch selectivity of the sacrificial film 170 with respect to the work function metal layer 160 and the first sacrificial film pattern 181, thereby forming the first insulating film pattern 171. A portion of the insulating film 170 (see FIG. 5) which is formed higher than the second sacrificial film pattern 182 is etched using the etch selectivity of the insulating film 170 with respect to the work function metal layer 160 and the second sacrificial film pattern 182, thereby forming the second insulating film pattern 172. According to an embodiment, topmost surfaces (e.g., two ends) of the first and second insulating film patterns 171 and 172 may be located at the same or substantially the same height as top surfaces of the first and second sacrificial film patterns 181 and 182, respectively, as shown in FIG. 6.

Referring to FIG. 7, the work function metal layer 160 formed higher than the first and second insulating film patterns 171 and 172 is selectively etched, thereby forming first and second work function metal patterns 161 and 162 respectively having topmost surfaces disposed in the first and second trenches 112 and 114, respectively. A portion of the work function metal layer 160 which is formed higher than the first insulating film pattern 171 is etched using the etch selectivity of the work function metal layer 160 with respect to the second conductive film 150, the first insulating film pattern 171 and the first sacrificial film pattern 181, thereby forming the first work function metal pattern 161. A portion of the work function metal layer 160 which is formed higher than the second insulating film pattern 172 is etched using the etch selectivity of the work function metal layer 160 with respect to the second conductive film 150, the second insulating film pattern 172 and the second sacrificial film pattern 182, thereby forming the second work function metal pattern 162. As shown in FIG. 7, a topmost surface (e.g., two ends) of the first work function metal pattern 161 may be located at the same or substantially the same height as the topmost surface (e.g., two ends) of the first insulating film pattern 171 and the top surface of the first sacrificial film pattern 181, and a topmost surface (e.g., two ends) of the second work function metal pattern 162 may be located at the same or substantially the same height as the topmost surface (e.g., two ends) of the second insulating film pattern 172 and the top surface of the second sacrificial film pattern 182.

Referring to FIG. 8, the first and second insulating film patterns 171 and 172 respectively formed on the first and second work function metal patterns 161 and 162 and the first and second sacrificial film patterns 181 and 182 are removed. The first and second sacrificial film patterns 181 and 182 are etched using their etch selectivity with respect to the second conductive film 150. According to an embodiment, the first and second sacrificial film patterns 181 and 182 are etched using the first and second insulating film patterns 171 and 172 as etch stop films, respectively. Accordingly, the first and second sacrificial film patterns 181 and 182 are removed, and the first and second insulating film patterns 171 and 172 are etched using their etch selectivity with respect to the second conductive film 150. According to an embodiment, the first and second insulating film patterns 171 and 172 are etched using the first and second work function metal patterns 161 and 162 as etch stop films, respectively. Accordingly, the first and second insulating film patterns 171 and 172 are

removed, and the first and second work function metal patterns 161 and 162 remain in the first and second trenches 112 and 114, respectively.

Referring to FIG. 9, the first work function metal pattern 161 formed in the first trench 112 is removed. In an embodiment, the removed first work function metal pattern 161 is a P-type work function metal pattern. According to an embodiment, the removal process can be modified or omitted depending on the characteristics of the work function metal pattern 161.

Referring back to FIG. 1, a first metal gate structure is formed in the first trench 112, and a second metal gate structure is formed on the second work function metal pattern 162 in the second trench 114. The first and second metal gate structures are planarized until the interlayer insulating film 110 is exposed, thereby forming a gate insulating film pattern 131, first and second conductive film patterns 141 and 151, and first and second metal gate structure patterns 200 and 210.

A semiconductor device according to an embodiment of the present invention is described with reference to FIG. 10.

FIG. 10 is a cross-sectional view illustrating a semiconductor device according to an embodiment of the present invention.

Referring to FIG. 10, an interlayer insulating film 110 may include a third trench 116 which is formed on a third region III of a semiconductor substrate 100 and which has a first width CL1 and a fourth trench 118 which is formed on a fourth region IV of the semiconductor substrate 100 and which has a second width CL2. According to an embodiment, each of the first width CL1 and the second width CL2 may be equal or substantially equal to a channel length of a transistor. According to an embodiment, the first width CL1 and the second width CL2 may be different from each other. According to an embodiment of the present invention, the first width CL1 may be smaller than the second width CL2 as shown in FIG. 10.

According to an embodiment, a PFET may be formed on each of the third region III and the fourth region IV of the semiconductor substrate 100. The PFET formed on each of the third and fourth regions III and IV may include a third or fourth work function metal pattern 163 or 164. According to an embodiment, two ends of each of the third and fourth work function metal patterns 163 and 164 are lower in height than top surfaces of the third and fourth trenches 116 and 118. According to an embodiment, a first depth D1 from a top surface of the interlayer insulating film 110 (e.g., a top surface of the third trench 116) to a topmost surface (e.g., two ends) of the third work function metal pattern 163 may be different from a second depth D2 from the top surface of the interlayer insulating film 110 (e.g., a top surface of the fourth trench 118) to a topmost surface (e.g., two ends) of the fourth work function metal pattern 164. According to an embodiment, when the first width CL1 is smaller than the second width CL2 as shown in FIG. 10, the first depth D1 may be smaller than the second depth D2. According to an embodiment, the difference between the first depth D1 and the second depth D2 may arise since the degree of etch of a work function metal layer 160 (e.g., as shown in FIG. 11) may vary according to the channel length of a transistor formed by a method of manufacturing a semiconductor device according to an embodiment of the present invention.

A method of manufacturing a semiconductor device according to an embodiment of the present invention is described with reference to FIGS. 4, and 10 through 13.

FIGS. 11 through 13 are cross-sectional views illustrating intermediate processes included in a method of manufacturing a semiconductor device according to an embodiment of the present invention.

Referring to FIG. 11, an interlayer insulating film 110 formed on a semiconductor substrate 100 is prepared. The interlayer insulating film 110 includes a third trench 116 having a first width CL1 and a fourth trench 118 having a second width CL2 which is greater than the first width CL1. A spacer 115 made of an insulating material may be placed on two opposite sides of each of the third trench 116 and the fourth trench 118. An interface film pattern 120, a gate insulating film 130, a first conductive film 140, a second conductive film 150, a work function metal layer 160, an insulating film 170, and a sacrificial film 180 are sequentially formed in each of the third and fourth trenches 116 and 118. According to an embodiment, the preparation or formation of the interlayer insulating film 110, the trenches 116 and 118, the spacer 115, the interface film pattern 120, the gate insulating film 130, the first conductive film 140, the second conductive film 150, the work function metal layer 160, the insulating film 170, and the sacrificial film 180 may be performed by the same or substantially the same processes described in connection with FIGS. 1 to 9.

The sacrificial film 180 is etched, thereby forming a third sacrificial film pattern 183 with a top surface disposed in the third trench 116 and a fourth sacrificial film pattern 184 with a top surface disposed in the fourth trench 118.

The sacrificial film 180 formed in the fourth trench 118 has a wider cross-sectional area which contacts an etchant than the sacrificial film 180 formed in the third trench 116. Therefore, even when the sacrificial film 180 formed in the fourth trench 118 and the sacrificial film 180 formed in the third trench 116 are etched for the same period of time, the sacrificial film 180 formed in the fourth trench 118 may be etched more. Accordingly, the fourth sacrificial film pattern 184 formed in the fourth trench 118 may be lower in height than the third sacrificial film pattern 183 formed in the third trench 116 as shown in FIG. 11.

Referring to FIG. 12, the insulating film 170 formed higher than the third and fourth sacrificial film patterns 183 and 184 is selectively etched forming third and fourth insulating film patterns 173 and 174 in the third and fourth trenches 116 and 118, respectively. Since the fourth sacrificial film pattern 184 is lower than the third sacrificial film pattern 183, a topmost surface (e.g., two ends) of the fourth insulating film pattern 174 may be formed lower than a topmost surface (e.g., two ends) of the third insulating film pattern 173.

Referring to FIG. 13, the work function metal layer 160 formed higher than the third and fourth insulating film patterns 173 and 174 is selectively etched, thereby forming a third work function metal pattern 163 with a top surface disposed in the third trench 116 and a fourth work function metal pattern 164 with a top surface disposed in the fourth trench 118. Since the fourth sacrificial film pattern 184 and the fourth insulating film pattern 174 are lower in height than the third sacrificial film pattern 183 and the third insulating film pattern 173, a topmost surface (e.g., two ends) of the fourth work function metal pattern 164 may be formed lower than a topmost surface (e.g., two ends) of the third work function metal pattern 163.

Referring to FIG. 10, a metal gate structure pattern 210 is formed in each of the third trench 116 and the fourth trench 118 and fills each of the third trench 116 and the fourth trench 118.

Hereinafter, a semiconductor device according to an embodiment of the present invention is described with reference to FIG. 14.

FIG. 14 is a circuit diagram illustrating a semiconductor device according to an embodiment of the present invention. According to an embodiment, a static random access memory

(SRAM) is described below as an example of a semiconductor device. However, the embodiments of the present invention is not limited to the SRAM.

Referring to FIG. 14, the semiconductor device may include two inverters, e.g., first and second inverters INV1 and INV2 connected in parallel between a power node Vcc and a ground node Vss and first and second transmission transistors T1 and T2 which are connected to output nodes NC1 and NC2 of the first and second inverters INV1 and INV2, respectively. The first transmission transistor T1 and the second transmission transistor T2 may be connected to a bit line BL and a complementary bit line BL/, respectively. A gate of the first transmission transistor T1 and a gate of the second transmission transistor T2 may be connected to word lines WL1 and WL2, respectively.

The first inverter INV1 may include a first load transistor T5 and a first driving transistor T3 connected in series to each other, and the second inverter INV2 may include a second load transistor T6 and a second driving transistor T4 connected in series to each other. An input node of the first inverter INV1 may be connected to the output node NC2 of the second inverter INV2, and an input node of the second inverter INV2 may be connected to the output node NC of the first inverter INV1, and thus, the first inverter INV1 and the second inverter INV2 may form one latch circuit.

According to an embodiment, at least one of the first load transistor T5 and the second load transistor T6 may be a PFET (P-type Field Effect Transistor) according to an embodiment of the present invention, and at least one of the first transmission transistor T1, the second transmission transistor T2, the first driving transistor T3 and the second driving transistor T4 may be an NFET (N-type Field Effect Transistor) according to an embodiment of the present invention.

Hereinafter, a semiconductor device according to an embodiment of the present invention is described with reference to FIG. 15.

FIG. 15 is a cross-sectional view illustrating a semiconductor device according to an embodiment of the present invention.

Referring to FIG. 15, a semiconductor substrate 100 of the semiconductor device may include a fifth region V, a sixth region VI, and a seventh region VII. According to an embodiment, the fifth region V and the sixth region VI may be memory regions in which, e.g., the SRAM described above in connection with FIG. 14 is formed, and the seventh region VII may be a peripheral circuit region. The peripheral circuit region may include an input/output (I/O) region. The seventh region VII may have a lower density and a wider gap between elements than the fifth region V and the sixth region VI.

According to an embodiment, an NFET (N-type Field Effect Transistor) and a PFET (P-type Field Effect Transistor) may be formed in the fifth region V and the sixth region VI, respectively. In the seventh region VII, a PFET (P-type Field Effect Transistor) having a greater channel length than a channel length of the PFET formed in the sixth region VI may be formed in the form of a logic element.

Hereinafter, an electronic system to which a semiconductor device according to an embodiment of the present invention is applied is described with reference to FIG. 16.

FIG. 16 is a block diagram illustrating an electronic system 900 to which a semiconductor device according to an embodiment of the present invention is applied.

Referring to FIG. 16, the electronic system 900 may include a memory system 912, a processor 914, a random access memory (RAM) 916, and a user interface 918. According to an embodiment, examples of the electronic system 900 may include a mobile device and a computer.

11

The memory system **912**, the processor **914**, the RAM **916**, and the user interface **918** may perform data communication with each other using a bus **920**. The processor **914** may execute programs and may control the electronic system **900**. The RAM **916** can be used as an operation memory of the processor **914**.

At least one of the processor **914**, the RAM **916**, and/or the memory system **912** may include a semiconductor device according to an embodiment of the present invention. In an embodiment of the present invention, the processor **914** and the RAM **916** may be included in one package.

The user interface **918** may be used to input or output data to/from the electronic system **900**. The memory system **912** may store codes for operating the processor **914**, data processed by the processor **914**, or data input from an external source. The memory system **912** may include a controller and a memory.

In concluding the detailed description, those skilled in the art will appreciate that many variations and modifications can be made to the embodiments without substantially departing from the principles of the present invention. Therefore, the disclosed embodiments of the invention are used in a generic and descriptive sense only and not for purposes of limitation.

What is claimed is:

1. A semiconductor device comprising:

a substrate including a first surface;

an inter-layer insulating film disposed on the first surface of the substrate, the inter-layer insulating film including a first trench on a first region of the substrate and a second trench on a second region of the substrate;

a first work-function metal pattern disposed in the first trench;

a second work-function metal pattern disposed in the second trench;

a first metal gate structure pattern disposed in the first trench and filling the first trench, the first metal gate structure pattern covering the first work-function metal pattern; and

a second metal gate structure pattern disposed in the second trench and filling the second trench, the second metal gate structure pattern covering the second work-function metal pattern,

wherein a first depth of the first metal gate structure pattern is greater than a second depth of the first metal gate structure pattern, the first depth of the first metal gate structure pattern being measured from a center of a surface of the first metal gate structure pattern, the second depth of the first metal gate structure pattern being measured from a first edge of the surface of the first metal gate structure pattern, the first depth of the first metal gate structure pattern is greater than a third depth of the first metal gate structure pattern, the third depth of the first metal gate structure pattern being measured from a second edge of the surface of the first metal gate structure pattern, the second edge of the surface of the first metal gate structure pattern being opposite to the first edge of the surface of the first metal gate structure pattern,

a first depth of the second metal gate structure pattern is greater than a second depth of the second metal gate structure pattern, the first depth of the second metal gate structure pattern being measured from a center of a surface of the second metal gate structure pattern, the second depth of the second metal gate structure pattern being measured from a first edge of the surface of the second metal gate structure pattern, and the first depth of the second metal gate structure pattern is greater than a

12

third depth of the second metal gate structure pattern, the third depth of the second metal gate structure pattern being measured from a second edge of the surface of the second metal gate structure pattern, the second edge of the surface of the second metal gate structure pattern being opposite to the first edge of the surface of the second metal gate structure pattern.

2. The semiconductor device of claim 1, wherein the first work-function metal pattern and the second metal gate structure pattern have substantially the same conductivity.

3. The semiconductor device of claim 1, wherein the first work-function metal pattern does not extend up to a top surface of the inter-layer insulating film, the top surface of the inter-layer insulating film being opposite to a bottom surface of the inter-layer insulating film that contacts to the first surface of the substrate.

4. The semiconductor device of claim 3, wherein the second work-function metal pattern does not extend up to the top surface of the inter-layer insulating film.

5. The semiconductor device of claim 1, wherein each of the first work-function metal pattern and the second work-function metal pattern is U-shaped.

6. The semiconductor device of claim 1, wherein a maximum height of the first work-function metal pattern is greater than a maximum height of the second work-function metal pattern.

7. The semiconductor device of claim 6, wherein a width of the second trench is greater than a width of the first trench.

8. The semiconductor device of claim 1, further comprising: a first conductive film patterns disposed in the first trench and in the second trench; and a second conductive film patterns formed on the first conductive film patterns in the first trench and the second trench, wherein the first conductive films include a first material and the second conductive films include a second material different from the first material.

9. A semiconductor device comprising: a substrate including a first surface; an inter-layer insulating film disposed on the first surface of the substrate, the inter-layer insulating film including a first trench on a first region of the substrate, a second trench on a second region of the substrate and a third trench on a third region of the substrate; a first work-function metal pattern disposed in the first trench; a second work-function metal pattern disposed in the second trench; a first metal gate structure pattern disposed in the first trench and filling the first trench, the first metal gate structure pattern covering the first work-function metal pattern; a second metal gate structure pattern disposed in the second trench and filling the second trench, the second metal gate structure pattern covering the second work-function metal pattern; and a third metal gate structure pattern disposed in the third trench and filling the third trench, wherein a first depth of the first metal gate structure pattern is greater than a second depth of the first metal gate structure pattern, the first depth of the first metal gate structure pattern being measured from a center of a surface of the first metal gate structure pattern, the second depth of the first metal gate structure pattern being measured from a first edge of the surface of the first metal gate structure pattern, and the first depth of the first metal gate structure pattern is greater than a third depth of the first metal gate structure pattern, the third depth of the first metal gate structure pattern being measured from a second edge of the surface of the first metal gate structure pattern, the second edge of the surface of the first metal gate structure pattern being opposite to the first edge of the surface of the first metal gate structure pattern, a first depth of the second metal gate structure pattern is greater than a second depth of the second metal gate structure pattern, the first depth of the second metal gate structure

13

pattern being measured from a center of a surface of the second metal gate structure pattern, the second depth of the second metal gate structure pattern being measured from a first edge of the surface of the second metal gate structure pattern, and the first depth of the second metal gate structure pattern is greater than a third depth of the second metal gate structure pattern, the third depth of the second metal gate structure pattern being measured from a second edge of the surface of the second metal gate structure pattern, the second edge of the surface of the second metal gate structure pattern being opposite to the first edge of the surface of the second metal gate structure pattern.

10. The semiconductor device of claim 9, wherein a depth of the third metal gate structure pattern is substantially the same regardless of a measuring point on a surface of the third metal gate structure pattern.

11. The semiconductor device of claim 9, wherein the first work-function metal pattern does not extend up to a top surface of the inter-layer insulating film, the top surface of the inter-layer insulating film being opposite to a bottom surface of the inter-layer insulating film that contacts to the first surface of the substrate, and the second work-function metal pattern does not extend up to the top surface of the inter-layer insulating film.

12. The semiconductor device of claim 9, wherein a P-type field effect transistor (PFET) is formed in each of the first region and in the second region, and a N-type field effect transistor (NFET) is formed in the third region.

13. The semiconductor device of claim 9, wherein a maximum height of the first work-function metal pattern is greater than a maximum height of the second work-function metal pattern.

14. The semiconductor device of claim 13, wherein a width of the second trench is greater than a width of the first trench.

15. The semiconductor device of claim 14, wherein the first region and the third region are memory regions where a memory device is formed, and the second region is a peripheral circuit region where a peripheral circuit is formed.

16. The semiconductor device of claim 14, wherein the second region has a lower density and a wider gap between elements than the first region and the third region.

17. A semiconductor device comprising: a substrate including a first surface; an inter-layer insulating film disposed on the first surface of the substrate, the inter-layer insulating film including a first trench on a first region of the substrate and a second trench on a second region of the substrate; a first work-function metal pattern disposed in the first trench; a second work-function metal pattern disposed in the second trench; a first metal gate structure pattern disposed in the first trench and filling the first trench, the first metal gate structure pattern covering the first work-function metal pattern; and a second metal gate structure pattern disposed in the second trench and filling the second trench, the second metal gate structure pattern covering the second work-function metal pattern, wherein the first work-function metal pattern does not extend up to a top surface of the inter-layer insulating film, the top surface of the inter-layer insulating film being opposite to a bottom surface of the inter-layer insulating film that contacts to the first surface of the substrate, the second work-function metal pattern does not extend up to the top surface of the inter-layer insulating film, a maximum height of the first work-function metal pattern is greater than a maximum height of the second work-function metal pattern, and a width of the second trench is greater than a width of the first trench.

14

tern; and a second metal gate structure pattern disposed in the second trench and filling the second trench, the second metal gate structure pattern covering the second work-function metal pattern, wherein the first work-function metal pattern does not extend up to a top surface of the inter-layer insulating film, the top surface of the inter-layer insulating film being opposite to a bottom surface of the inter-layer insulating film that contacts to the first surface of the substrate, the second work-function metal pattern does not extend up to the top surface of the inter-layer insulating film, a maximum height of the first work-function metal pattern is greater than a maximum height of the second work-function metal pattern, and a width of the second trench is greater than a width of the first trench.

18. The semiconductor device of claim 17, wherein a first depth of the first metal gate structure pattern is greater than a second depth of the first metal gate structure pattern, the first depth of the first metal gate structure pattern being measured from a center of a surface of the first metal gate structure pattern, the second depth of the first metal gate structure pattern being measured from a first edge of the surface of the first metal gate structure pattern, the first depth of the first metal gate structure pattern is greater than a third depth of the first metal gate structure pattern, the third depth of the first metal gate structure pattern being measured from a second edge of the surface of the first metal gate structure pattern, the second edge of the surface of the first metal gate structure pattern being opposite to the first edge of the surface of the first metal gate structure pattern, a first depth of the second metal gate structure pattern is greater than a second depth of the second metal gate structure pattern, the first depth of the second metal gate structure pattern being measured from a center of a surface of the second metal gate structure pattern, the second depth of the second metal gate structure pattern being measured from a first edge of the surface of the second metal gate structure pattern, and the first depth of the second metal gate structure pattern is greater than a third depth of the second metal gate structure pattern, the third depth of the second metal gate structure pattern being measured from a second edge of the surface of the second metal gate structure pattern, the second edge of the surface of the second metal gate structure pattern being opposite to the first edge of the surface of the second metal gate structure pattern.

19. The semiconductor device of claim 17, wherein the first work-function metal pattern and the second metal gate structure pattern have substantially the same conductivity.

20. The semiconductor device of claim 17, wherein a P-type field effect transistor (PFET) is formed in each of the first region and in the second region.

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